11 Site-Specific Yield Histories On a SE Coastal Plain Field

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Site-specific farming research at Florence, SC, began in 1984 with a topographic survey and subsequent detailed soil mapping by local USDA-SCS staff. An area that was representative of the coastal plain soil types was planted to corn in 1985. Since then, five crops of corn (*Zea mays*), three of wheat (*Triticum aestivum*), three of soybean (*Glycine max*), and one of grain sorghum (*Sorghum bicolor*) have been grown. Harvested plots were located using surveying techniques, and the plot outlines were overlaid onto the soil map to determine the corresponding soil map unit. To date, over 3000 plots have been measured. Analysis of variance indicated that differences in mean yields were significant, but inspection suggested that intra-map unit variance was nearly as large as inter-map unit variance. Attempts to explain variation in yield using both statistical regression and mechanistic modeling were not successful. Geostatistical analysis produced the expected patterns of high and low yield, but yr-to-yr variation in mean yield masked underlying patterns. A method developed to normalize annual variability in mean yield, while accounting for shifts in location of sampled yields, produced composite maps of relative yield. These maps should be useful for setting target yields of various soil types, thus allowing calculation of fertilizer requirements. This research has provided much new knowledge about inherent variation expected for these soils, as well as having started a baseline from which to judge annual variability of yield for regional soils and crops. Interpretation of these results and extension of the information to make fertility and irrigation recommendations depends on the successful quantitative description of the causes of variation among soil types under regional climate. Despite problems encountered during this work, mechanistic simulation models appear to be the most likely tool to achieve this objective.

HISTORY AT FLORENCE

Field Studies

Site-specific farming research at Florence grew out of the erosion-productivity research topic in the early 1980's. At that time, the emphasis was on variation among soil types caused by historical erosion on sloping land in the Piedmont. The topography is more level in the Coastal Plain, and soil-to-soil variability results from soil genetic factors in addition to erosion. A predominant feature in this geographic area that remains unexplained is the Carolina Bay, which is a circular, shallow depression ringed by often inhospitable soils. The productivity of the bays is so poor that most are left to weeds. Whether the bays are left out of production or farmed, the reduction in productivity over the total area farmed is not trivial. Over 12% of the Florence location's experimental area are soils contained in or associated with Carolina Bays.

In 1984, the local USDA-SCS staff mapped the laboratory's experimental area, starting from a 15–m survey grid. Resolution was finer if changes in soil map unit were found between the grid points (USDA-SCS, 1986). At each auger hole, the classifiers also recorded the depth to the clay layer. This depth, at which most coastal plain soils change from >70% sand to >40% clay, is an easily-identified characteristic, and is used to distinguish among several soil types. The topographic map, the soils map, and the map of the depth to the clay layer were stored in computer format for later analysis (see Fig. 11–1 and Table 11-1 for information on soils).

In 1985, we planted corn on one representative 8-ha field, using uniform, conventional methods typical of local farmers. In similar fashion, five crops of corn, four of wheat, three of soybean, and one of grain sorghum have been grown on this area. For all crops, harvest plots were positioned using survey techniques, and the corresponding map units were identified from the soil map (e.g., Fig. 11–2). Over 3000 site-specific yields have been so obtained.

Statistical Analysis of Map Unit Means

Consistent with the erosion–productivity studies of the time, our early analyses focussed on the variations among map unit mean yields. Differences among map unit means for the first 5 yr were significant according to analysis of variance (Karlen et al. 1988; 1990), but later harvests were less conclusive. Tables 11-2 and 11-3 show soil map units, expected yields (from the USDA-SCS soil survey productivity rating), and measured mean yields for the cropping sequence.

Closer inspection of the yields for a map unit indicated that some inclusions were more productive than others. In some cases, the primary distinguishing characteristic between inclusions appeared to be the depth to clay. Except for a few soils, however, attempts to correlate yield to depth of clay were not successful (Fig. 11–3). Other possible causes of the variation included existence of an eluviated horizon, subsoil acidity, and non-uniform hardpan disruptionby in-row subsoiling. The interactions between these factors and depth

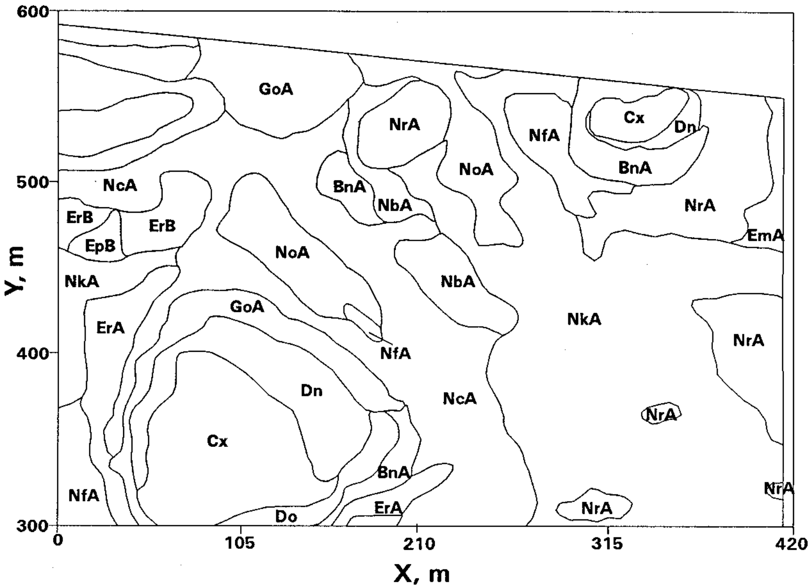

Fig. 11–1. Soil map of the fields used for site-specific farming research at the Florence, SC, USDA facility.

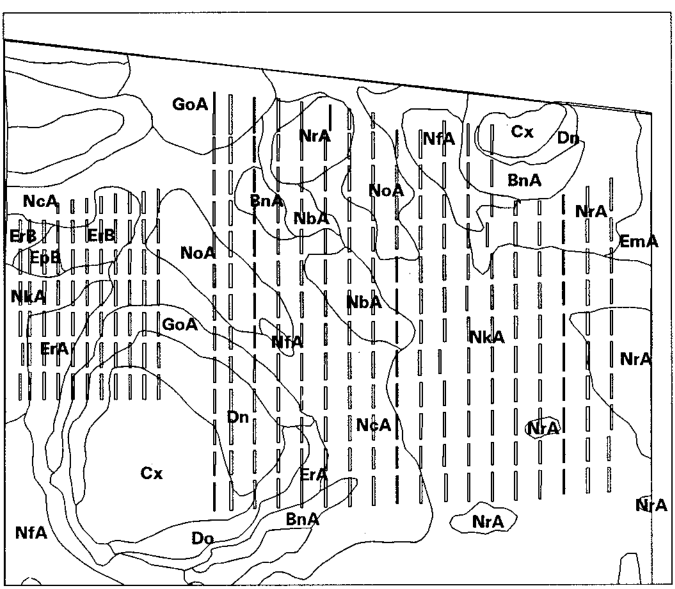

Fig. 11–2. Map of 1987 wheat harvest plots overlaid on the soils map.

Table 11–1. Proportionate distribution of soils within the 24-ha area at the Coastal Plains Research Center where the 8-ha experimental field was located.

Symbol	Soil classification	%
BnA	Bonneau Loamy fine sand (lfs), 0 to 2% slopes (Loamy, siliceous, thermic Grossarenic Paleudult†)	2.2
BoA	Bonneau Loamy sand (ls), 0 to 2% slopes, overwash (Loamy, siliceous, thermic Grossarenic Paleudult†)	0.2
Cx	Coxville Loam (Clayey, kaolinitic, thermic Typic Paleaquult)	4.5
Dn	Dunbar lfs (Clayey, kaolinitic, thermic Aeric Paleaquult)	2.2
Do	Dunbar lfs, overwash (Clayey, kaolinitic, thermic Aeric Paleaquult)	0.8
EmA	Emporia lfs, moderately thick surface, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	1.7
EpA	Emporia lfs, thick surface, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	2.5
EpB	Emporia lfs, thick surface, 2 to 4% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	0.2
ErA	Emporia fine sandy loam (fsl), 1 to 2% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	1.7
ErB	Emporia fsl, 2 to 4% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	6.0
ErD	Emporia fsl, 10 to 15% slopes (Fine-loamy, siliceous, thermic Typic Hapludult)	1.5
GoA	Goldsboro lfs, 0 to 2% slopes (Fine-loamy, siliceous, thermic Aquic Paleudult)	1.7
NbA	Noboco lfs, moderately thick surface, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult)	1.7
NcA	Noboco lfs, thick surface, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult)	7.9
NfA	Noboco fsl, 1 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult)	1.0

Table 11-1. Continued

NkA	Norfolk lfs, moderately thick surface, deep water table, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult‡)	47.7
NnA	Norfolk lfs, moderately thick surface, very deep water table, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult‡)	6.0
NoA	Norfolk lfs, thick surface, 0 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult‡)	4.5
NrA	Norfolk fsl, 1 to 2% slopes (Fine-loamy, siliceous, thermic Typic Paleudult‡)	5.2
W	Water	0.8

†Reclassified March 1990 to Loamy, siliceous, thermic Arenic Paleudult.
‡Reclassified March 1988 to Fine-loamy, siliceous, thermic Typic Kandiudult.

Table 11–2. Soil map units, productivity rating (USDA-SCS, 1986), and measured yields for the 5 corn seasons.

Soil	Productivity rating	Measured yield ± standard deviation				
		1985	1986	1988	1992	1993
	kg/ha			kg/ha		
BnA	5344			5104±1262	6543±1398	2232± 957
Cx	6916	3645± 963	728± 635	1364± 825	7802±1235	2456±1389
Dn	7230	3871± 921	163± 148	1192± 610	4889±2051	2751±1453
EpB	6287	7727± 978	2166± 254	3944± 604		
ErA	6916	7333± 738	2067± 349	3314± 722	6546± 405	2158± 251
ErB	6287	7686± 477	2187± 302	3775± 541		
GoA	7859	5097± 786	1329±1143	2102±1682	6275± 882	2230± 837
NbA	7230			4495± 548	8178± 480	3404± 681
NcA	7230	6038±1320	2228± 504	4160±1239	7497±1063	2629± 737
NfA	7230			4248± 560	7389± 909	1956± 628
NkA	6916	6806±1310	2738± 431	4471± 712	7609±1264	2262±1043
NoA	6916	8290± 57	2834± 489	4606± 671	7894± 995	2876± 819
NrA	6916		1496± 609	4378± 346	7209±1045	2452± 818
Mean		6319±1635	1865± 953	3510±1583	7310±1236	2481± 919
No. samples		130	145	331	256	209

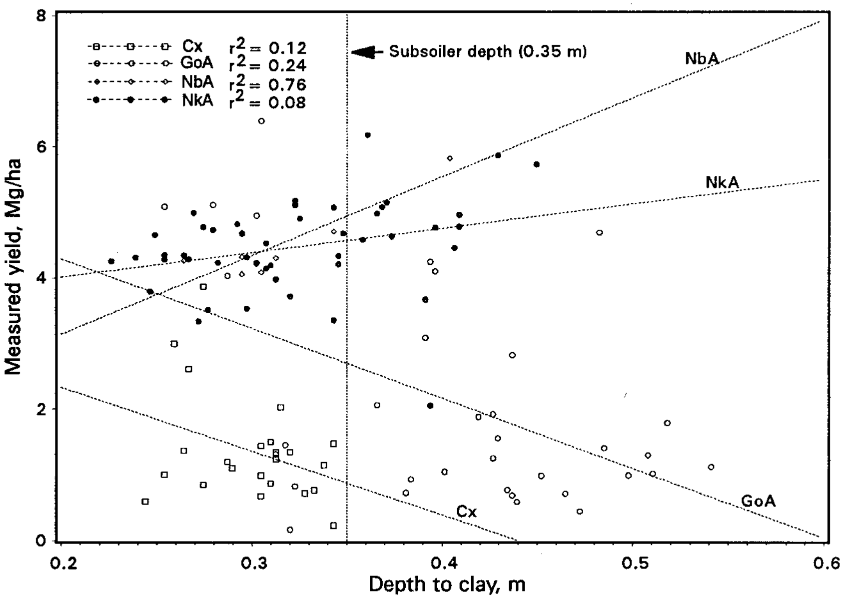

Fig. 11-3. Relationship of individual plot yields with depth to clay for the 1988 corn season.

Table 11–3. Expected yields (from soil survey productivity ratings), measured mean yields, and standard deviations for soybean and wheat grown on the various soil map units.

Soil	Soybean	Measured yield ± standard deviation			Wheat	Measured yield ± standard deviation		
	Rating	1989	1990	1991	Rating	1987	1989	1991
		kg/ha				kg/ha		
BnA	2021	1885±433	2497±117	1102±747		3815±1146	3808±713	1483±413
Cx	2695	2209±358	2491±301	1403±313	3368	3502± 299	4093±382	1431±432
Dn	3031	1827±313	2352±329	1796±156	3705	3715± 591	4133±485	.
Do	3031	1790±363	2316±271	1282±309	3705	.	3897±375	2112± 76
EpB	2021	.	.	.	3368	5053±1266	4711±230	.
ErA	2358	1867±229	1660±120	323±152	3705	5297± 844	4549±253	2706
ErB	2021	.	.	.	3368	6141± 195	4558±346	.
GoA	3031	1389±458	2545±301	1494±658	4042	4455± 810	3756±401	1486±298
NbA	3031	1918±341	2184±190	1788±356	4042	6229± 447	4298±438	2297±300
NcA	3031	1853±299	2368±224	1599±471	4042	5433± 734	4146±393	2053±355
NfA	3031	1711±281	2244±454	1072±510	4042	5261± 465	4049±424	2057±414
NkA	2695	2022±390	2000±460	912±654	4042	4529± 909	3961±764	1885±464
NoA	2695	1765±280	2353±319	1549±470	4042	5985± 446	4268±437	2027±373
NrA	2695	1794±373	2139±272	1376±608	4042	4816±1187	4026±637	2012±465
Mean		1841±387	2290±358	1395±606		4890±1052	4083±597	1967±445
No. samples		194	234	300		195	588	324

to clay were too complex to describe statistically. Describing the cause of this variation became the emphasis of the project. During this analysis, it became clear that yield variation within a map unit, or even within one inclusion of a map unit, could approach the variation among map units (Fig. 11–4).

Mechanistic Modeling of Map Unit Means

This emphasis on describing causes of the variation led to the acquiring, testing, and subsequent parameterization of the daily time step models of crop growth (Sadler et al., 1988): CERES-Maize (Jones & Kiniry, 1986), CERES-Wheat (Godwin et al., 1988), SORKAM (Rosenthal et al., 1989), CERES-Sorghum (Alagarswamy et al., 1988), and SOYGRO (Jones et al., 1989). Early data were more numerous and the yields were more varied for corn, so the initial effort concentrated on CERES-Maize. At that time, Versions 1.0 (Jones & Kiniry, 1986) and 2.0 (Ritchie et al., 1988) were both available. Sensitivity analyses indicated that combinations of parameters existed that would produce generally realistic yields, but attempts to match typical pedon descriptions to map unit mean yields were not successful (Fig. 11–5). In general, soils that did not have root-restricting horizons were adequately simulated, but soils with acidic subsoils or eluviated horizons were not. Algorithms were developed to produce estimates of rooting in horizons as a function of density, acidity, depth, and tillage. The accounting for root weighting in the CERES models, however, was not sufficient to prevent the simulated exploration by roots of these unexplored zones. Simulations were repeated for later versions (V2.10, Ritchie et al., 1989; V3.00 pre-release) with similar results, but this was expected because the rooting algorithm is common to all versions.

In addition, simulations during droughts indicated that the water balance was not simulated well because the model estimated too much infiltration during intense storms. For example, a 92-mm, 52-min duration storm occurred during the 1986 drought. The model simulated 22 mm of runoff, and 70 mm of infiltration. According to the model, that much infiltration was sufficient to carry the crop to the end of the season, and therefore simulated yields were about twice the measured ones. Qualitative observations of runoff, lower infiltration rates of local soils, lack of ponding except for a short time after the storm, and subsequent rapid onset of water stress all indicated that much more runoff occurred. Simulations using breakpoint rainfall and Green-Ampt methods resulted in a more likely outcome, which was about the reverse of the CERES result (Stone & Sadler, 1991). Reinsertion into CERES of lower rainfall totals, which forced infiltration to match the Green-Ampt results, produced simulated yields about halfway between the previously simulated and the measured yields. The authors of the models are addressing this rooting algorithm at this time.

Geostatistical Description of Spatial Yields

Concurrent with the later stages of the modeling effort, and following discussions during the first Site-Specific workshop (Sadler et al., 1992), a project was conducted to describe spatial variation using geostatistical methods (Sadler

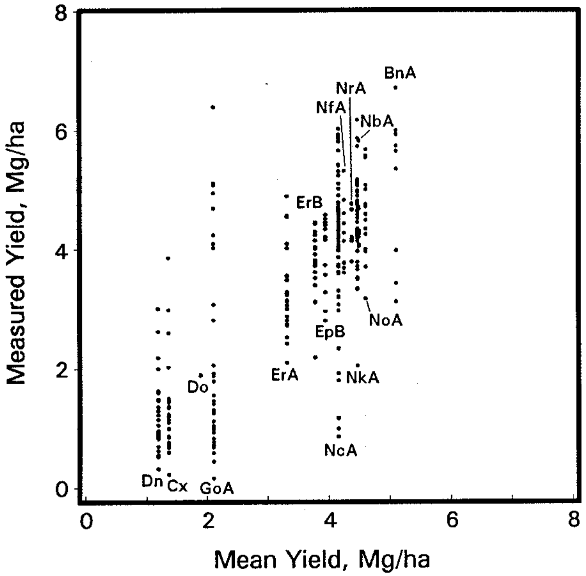

Fig. 11–4. Relationship of individual plot yields with the mean yield of the corresponding soil map unit for the 1988 corn season.

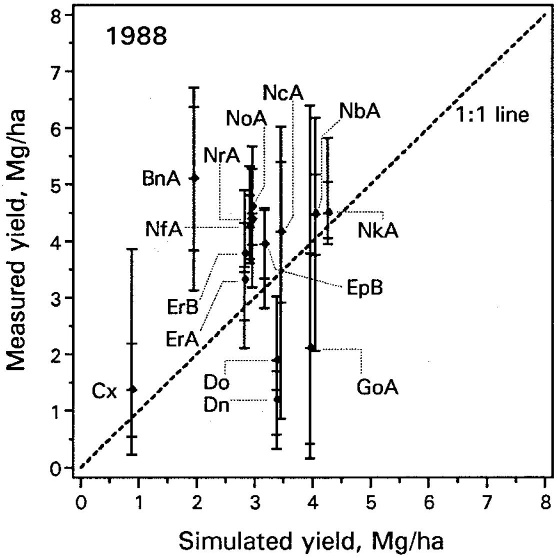

Fig. 11–5. Simulated and measured corn yield for the 1988 season.

& Busscher, 1992). Kriging of data from individual crop-yr produced yield maps (e.g., Figs. 11-6, 11-7). Typically, these maps were visually comparable, but clearly different from crop to crop (contrast Figs. 11-8, 11-9, and 11-10), and difficult to summarize into a single statement over all yrs for a single crop. If kriged interpolations were simply averaged for points across the field, the result would depend on the quality and reproducibility of the sampling scheme at the harvests. For example, consider a possible real-world case where a sample from a high-yielding yr is located near an interpolation point, but the sampling scheme skipped a low-yielding area nearby. The final yield estimate from that point would be high, as would the estimates from the area around the point. If data from a lower-yielding yr were available from within the area omitted from the high-yielding yr, one might conclude that the estimate from the high-yielding yr was biased higher because of the inclusion of high estimates across the zone. In fact, the kriged estimate was of less value because of distance from input data. A method was needed to account for the disparate locations of samples and to account for the resulting reduced confidence in the estimates when brought to a regular grid of varying distance from the samples.

A procedure was developed that normalized for yr-to-yr differences in mean yield, and produced an estimate that accounted for the location of the measurements and, therefore, quality of the interpolated estimates (Sadler et al., 1994). In brief, the method involves dividing individual plot yields by the mean yield for the yr, as suggested by Schnug et al. (1993), and then kriging the result. These normalized, or relative, yields can then be compared to other normalized yields on a standard grid. The problem of how to compute the average relative yield at an interpolation point was solved using the estimated variance of the kriged estimate, which is provided by the geostatistical software. The inverse of this variance was used as the weighting factor in a weighted average. The variance of the kriged estimate increases with distance from sample points, so by inversion, the weighting is strongest for information originating nearest the interpolated point. Using this procedure relieves one of the requirement to mask out areas that were sparsely sampled so that they will not overly influence the composite estimate. It allows data from multiple yrs to be aggregated into a single, objective yield map. The working map is of relative yield, which for our examples ranged ±0.4 from a mean of 1.0 (Figs. 11-8, 11-9, and 11-10). The only additional parameter needed beyond that required in a normal kriging process is an estimate of the expected mean yield, which conveniently corresponds to the farmer's target yield.

Sadler et al. (1994) examine differences between the weighted average yield map and individual yr yield maps. They also examine errors expected if, say, fertilization decisions were based on yield maps for individual yrs, relative yield maps, or the weighted-average-yield map. These decisions could be contrasted to decisions based on map unit productivity index ratings. Weighted average relative yields are shown for corn, wheat, and soybean in Figs 11-8, 11-9, and 11-10.

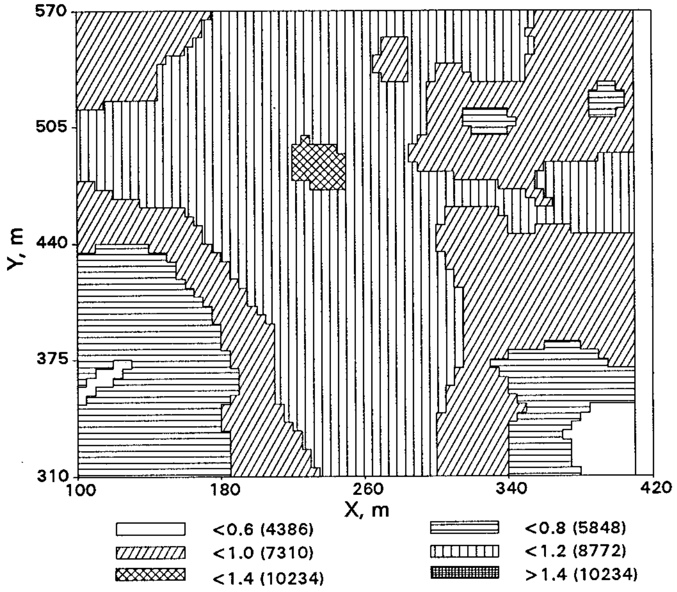

Fig. 11–6. Map of kriged corn yields from the 1992 season.

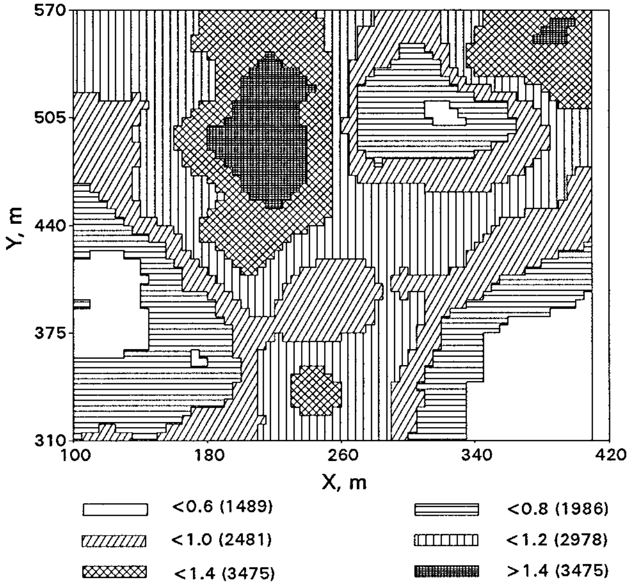

Fig. 11–7. Map of kriged corn yields from the 1993 season.

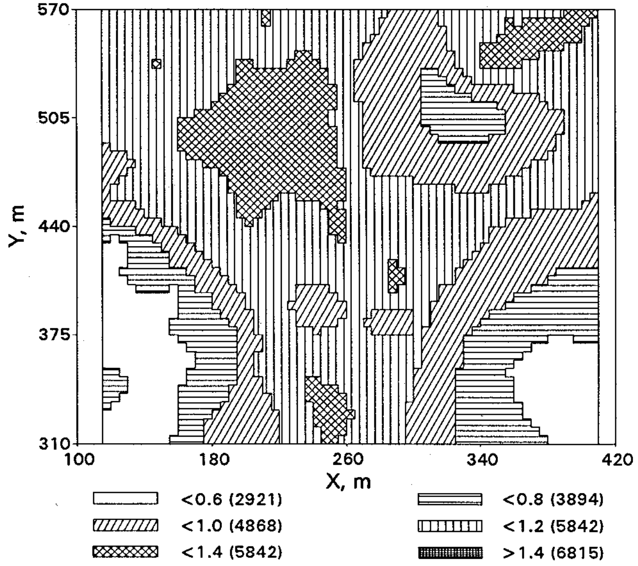

Fig. 11–8. Map of weighted mean corn yields, compiled from 3 seasons of yields on the larger field.

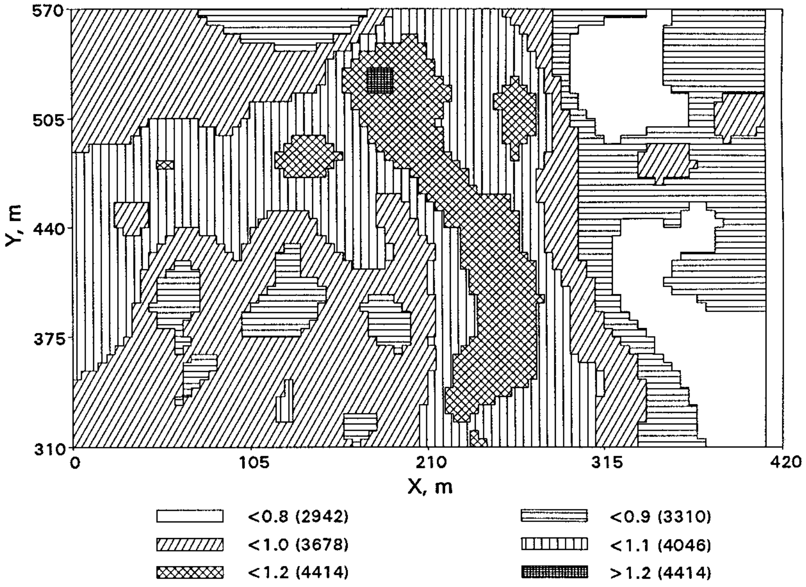

Fig. 11–9. Map of weighted mean wheat yields, compiled from 3 seasons of yields.

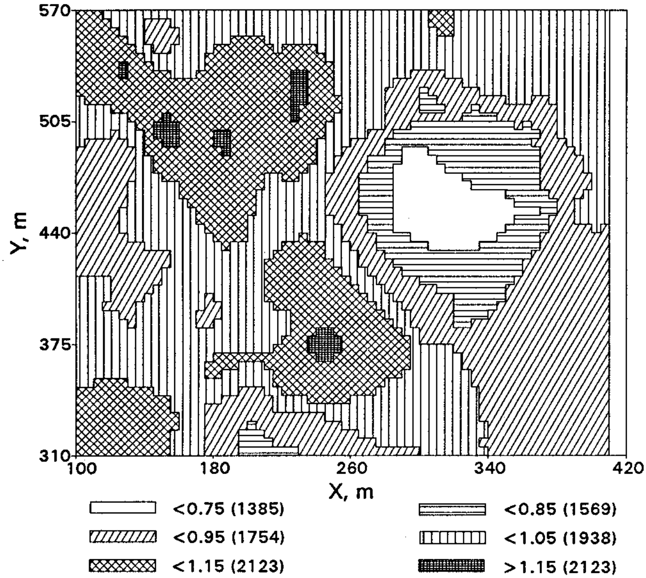

Fig. 11–10. Map of weighted mean soybean yields, compiled from 3 seasons of yields.

SUMMARY AND CONCLUSIONS

While the ongoing project will continue to provide insights into causes and effects of soil variability in the SE coastal plain, some conclusions have been obtained that will help direct future research at the location. First, the project has demonstrated the value of monitoring yields for multiple years. Second, it appears that limited progress can be made in quantitatively describing causes and effects of regional soil variability until mechanistic simulation models of crop growth can meet the water balance and can account for sub-optimal rooting conditions. Third, normalizing yield for annual variability shows some promise in improving utility of yield maps. Finally, geostatistical methods applied to normalized yield may allow composite summaries to be made of multiple-yr data.

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